

Interactive comment on “Tropospheric products of the 2nd European GNSS reprocessing (1996-2014)” by Jan Dousa et al.

Responses to Editor, Dr Olivier Bock.

Dear authors, please find below a few additional comments to those provided by the two referees.

1. You write that the EUREF recommendations are followed which specify that “weekly coordinates should be used to estimate tropospheric parameters on a daily basis” (L129) and that the coordinates were fixed to these values (L144). Did you fix the coordinates for all stations or only the fiducial stations? Fixing station heights is known to produce biases in ZTD estimates due to un-modelled station motions (tidal and non-tidal, e.g. seasonal) and other error sources (because of the correlation between estimated parameters). Abrupt changes and drifts over time that impact stations height would then also map into ZTD estimates. Can you comment on the uncertainty in the ZTD estimates, and possibly also gradients, due your specific processing strategy?

We understand the point and your concerns. However, first we had no choice but follow the EUREF guidelines for tropospheric estimates as our primary goal was the contribution to EUREF. And second, it is also well known that weekly coordinates estimated are more accurate than daily estimates which particularly concerns of the height component and the most one correlated with ZTD parameters. It is also known that ZTDs are temporally correlated up to 1-2 days (Stoew and Elgered, 2005) suggesting to use a longer period than a single day for a proper decorrelation of coordinates and tropospheric parameters. Thus, in the last step of our procedure, the tropospheric parameters on daily basis were estimated with tightly constrained weekly coordinates (for all the stations). We believe that any drift over time is handled in this way while abrupt changes could be difficult to handle anyway using daily solutions. On a weekly basis, we could additionally apply quality control based on residuals from weekly combination for identifying and rejecting outliers on a daily basis. Generally, it would be difficult to assess the uncertainty of ZTD and gradient estimates due to our specific strategy as we cannot easily separate and evaluate errors propagated into tropospheric parameters due to un-modelled day-to-week station motions. We believe the uncertainty of our specific strategy is comparable to or lower than the method simultaneously estimating coordinates and tropospheric parameters. As it concerns to any other error sources, e.g. such as from precise products, we are not happy they still contaminate our solution, however, it would not be more beneficial to assimilate them into daily station coordinates which might be the case.

2. The relevance of this study is that several processing variants are produced with the same software. The results are thus not obscured by inter-software biases. However, the discussion of results from the different variants is quite short in the manuscript. The accuracy of tropospheric parameters is only analysed based on Table 5 and Figure 5 and 6. Table 5 compares the biases and standard deviations over all stations and all times for the different variants. It is striking that the differences in these numbers are tiny. I would not be surprised that a spatialized analysis reveals significant impact of changing the cut-off angle and mapping functions at sites in different climatic regions, in mountainous areas, or close to the sea. If relevant, I suggest that you complement the paper with spatialized results.

We performed spatial and temporal analyses of all processed variants in order to assess the impact of different settings on tropospheric products. Zenith tropospheric delays from all variants were compared in such a way to enable assessing impact of any single processing change: 1) GO1-GO0 for mapping function and more precise a priori ZHD model, 2) GO2-GO1 and GO3-GO1 for different elevation angle cut-off, 3) GO4-GO1 for non-tidal atmospheric corrections, 4) GO5-GO4 for higher-order ionospheric corrections and, 5) GO6-GO4 for temporal resolution tropospheric horizontal gradients. Station-specific behavior is out of this paper and will be studied in future. New subsection (4.4) was added to the manuscript. However, we believe more detailed study on site-specific behaviour is out of the scope of this paper as it would require

more time for analysis and additional space for text and figures. We will certainly use the dataset for it in future.

3. Table 4 comparing the GOP solutions to the outdated EUREF repro1 is not relevant. This comparison might be done as an initial consistency check of the new solutions compared to the legacy EUREF reference. I thus suggest removing this figure and the related text from the manuscript.

Table 4 and related text comparing GOP Repro2 with EUREF Repro1 were removed from the manuscript.

4. The temporal homogeneity of long time series is crucial when trends are to be estimated. Given that there is presently a high interest of the GNSS/climate community in estimating trends, I think it would be useful to complement the results with an analysis of trends for the different processing variants. There are many questions like: which cut-off angle and mapping functions choose to get the most homogenous time series? What is the impact of changing quality in GNSS observations over time? Again, the conclusions might be station dependent and both overall and spatialized analyses might be necessary to document them properly.

We added an analysis of trends using different processing variants. The analysis was limited to 12 stations with the longest data time-series. Trends ranged from -0.05 to 0.38 mm/year with formal errors of 0.01-0.02 mm/year. The most significant impact was observed due to the changing elevation angle cut-off reaching differences up to 1 mm/year in ZTD while the impact of any other strategy change was below 0.5 mm/year only. The manuscript was completed by Section 5.

5. The impact of the temporal resolution of gradient parameters is intriguing. Indeed, better accuracy is expected when combining the 6-hourly to 24-hourly estimates. With 4 times more observations the standard deviation is expected to be divided by a factor of 2. However, according to Table 5 the improvement is only by a factor of 1.3 suggesting there is serial correlation in the errors. Is this reduction factor is uniformly distributed over stations and stable over time? Can you be more specific about the correlation between gradients and other parameters suggested in the manuscript? (L280 and 309)

You are right, the real factor of the improvement when using additional observations is lower than the one theoretically expected indicating the correlations in the errors. The factor was found generally stable over all stations when ranging from 1.03 to 1.65 with the mean value of 1.35. The description and discussions was completed (Section 4.3).

6. The drift in the gradient estimates at station MALL (Fig. 7) is impressive. How did the ZTD estimates evolve during the period when gradients drifted? Did you detect other cases like this? In the case of MALL the cause was identified as a tracking problem. Did you detect other causes which could produce such drifts in gradients or ZTDs? It would be interesting to include a check on gradients as part of a data screening method. I suggest considering this idea in the discussion.

ZTDs at MALL stations were affected significantly too. During the same period, the period, also yearly mean ZTD differences to ERA-Interim steadily changed from about 3 mm to about -12 mm and immediately dropping down to -2 mm in 2008 after the antenna change. Short note added to the manuscript (Section 6).

Although the station MALL represented an extreme case, biases at other stations were observed too, e.g. GOPE (1996-2002), TRAB (1999-2008), CREU (2000-2002), HERS (1999-2001), GAIA (2008-2014) and others. Site-specific, spatially or temporally correlated biases suggest different possible reasons such as site-instrumentation effects including the tracking quality and phase centre variation models, site-environment effects including multipath and seasonal variation (e.g. winter snow/ice coverage), edge-network effects when processing double-difference observations, spatially correlated effects in reference frame realization and possibly others. More detail investigation is out of the scope of this paper and will be studied in future. This short discussion added in manuscript (Section 6).

We fully agree that the assessing gradient parameters could be a valuable method as a part of ZTD data screening procedure. Short note added to the discussion (Section 6).

Other specific comments are given in the annotated PDF. Please also note the supplement to this comment <http://www.atmos-meas-tech-discuss.net/amt-2017-11/amt-2017-11-EC1-supplement.pdf>

All specific comments were carefully resolved too.

We would like to thank for the comments which helped us to improve the manuscript significantly.

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